Fermilab

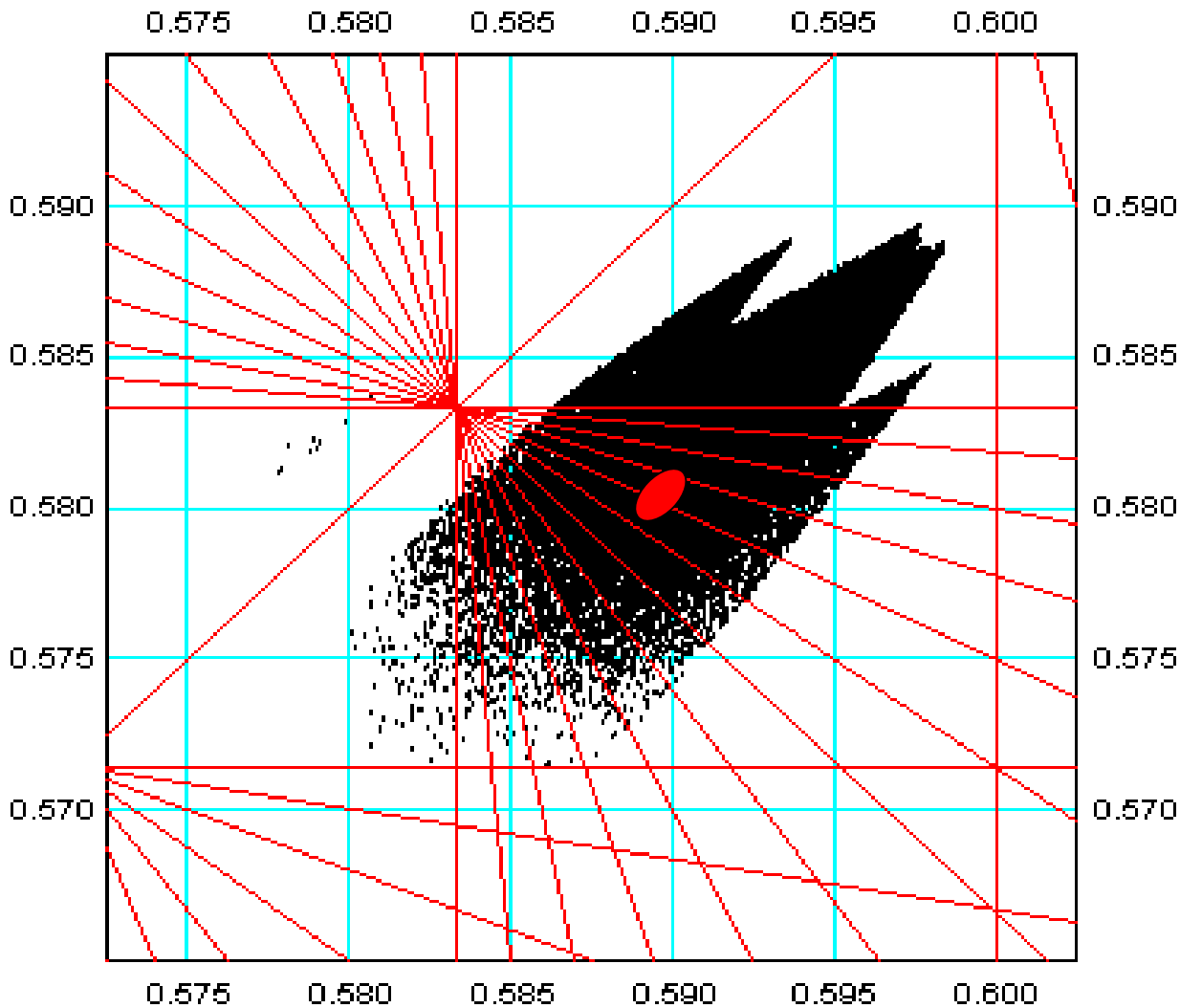
Beam-Beam Phenomena in the Tevatron or What We Need to Compensate

Vladimir Shiltsev

Content:

- Original Motivation for the BBC
- Beam-Beam Phenomena:
  - Beam Loss at 150 and on Ramp
  - Scallops
  - Antiproton Lifetime
  - Proton Lifetime
- Beam-beam compensation
  - possibilities
  - requirements

Pbar bunch tunes in collisions – Calc'd



P.Bagley

Yu.Alexahin

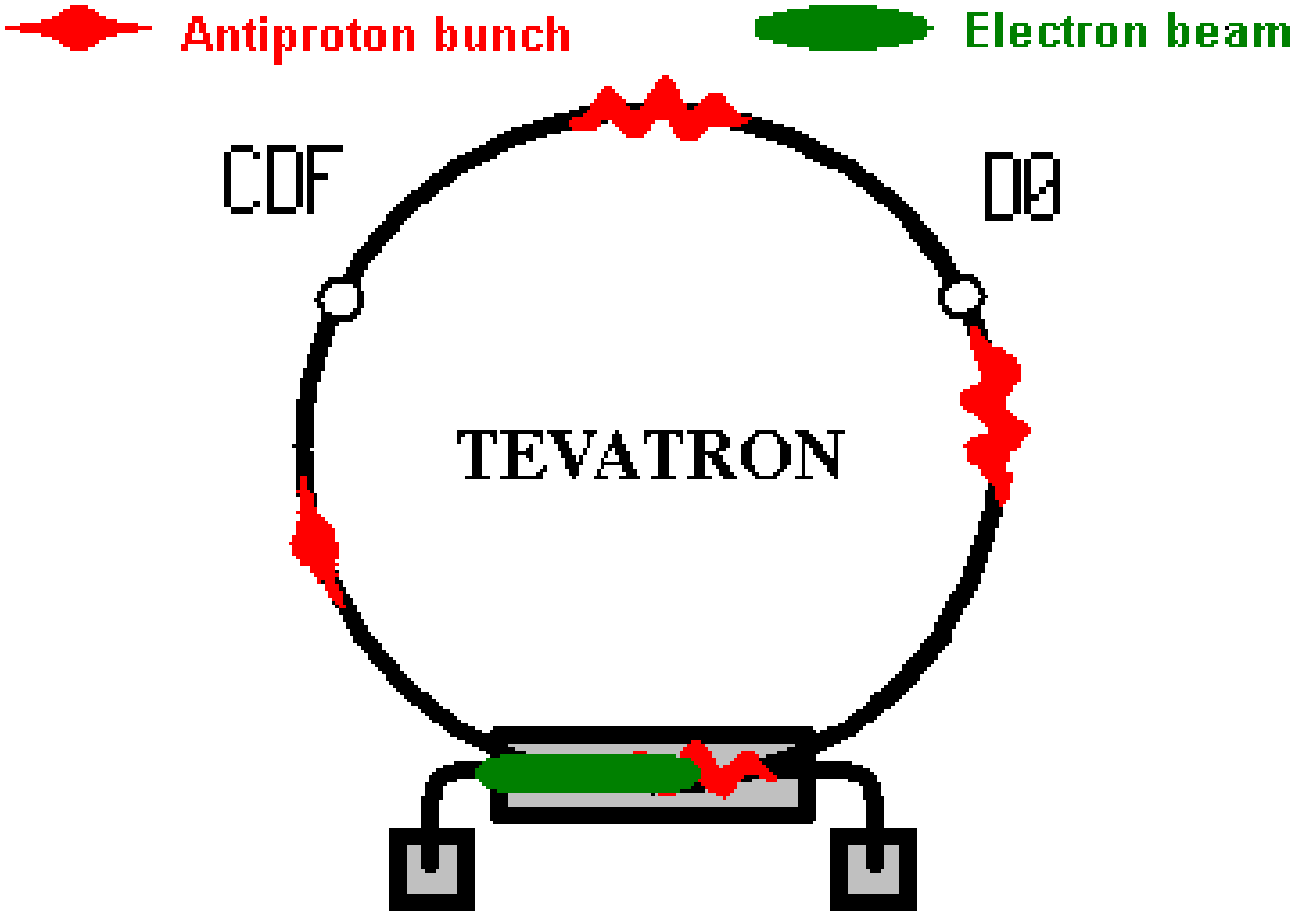
T.Sen

D.Shatilov

In 1996, P.Bagley found a good agreement between his calculations and measurements (though the lattice was somewhat different)

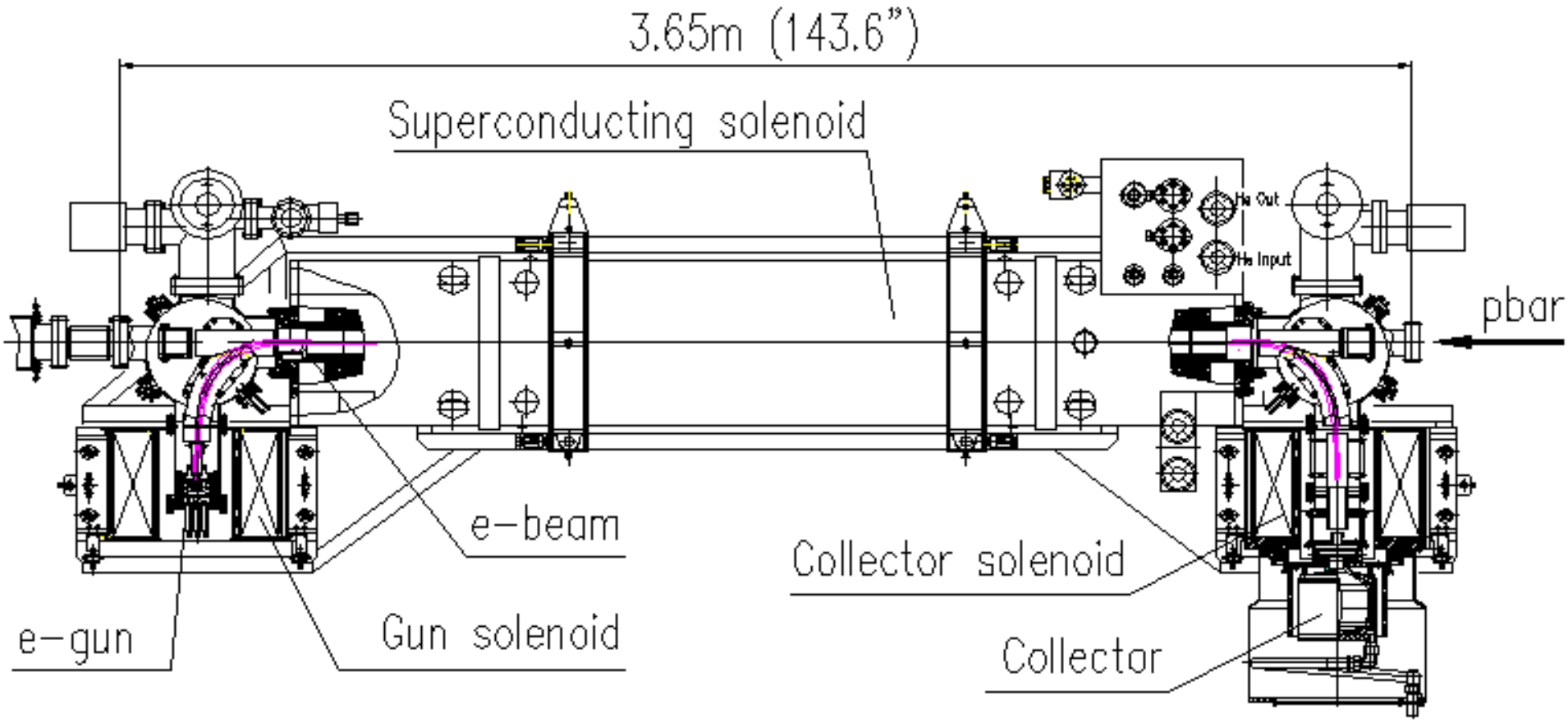
Proc. EPAC'96

Beam-Beam Compensation Idea



"…to compensate (in average) space charge forces of positively charged protons acting on antiprotons in the Tevatron by interaction with a negative charge of a low energy high-current electron beam " (1997)

Tevatron Electron Lens (TEL-1)



+ HV Modulator, HV+HC PSs, Cryo, QPs, Vacuum, Controls, Diagnostics, Cables

Tevatron Electron Lens at F48

Luminosity and Luminosity Integral

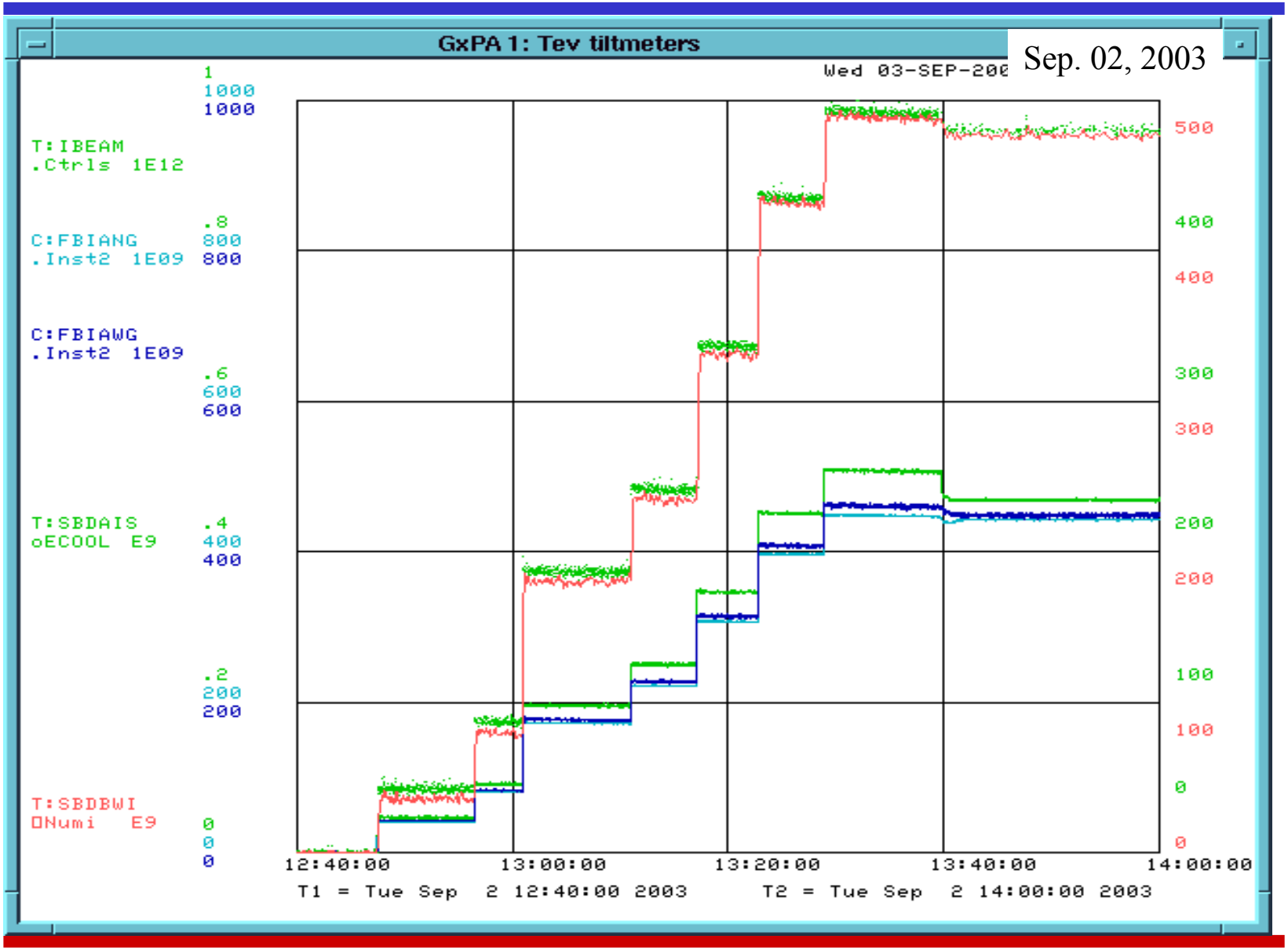
$$L = \frac{3\gamma\ f_0\ B\ N_{\bar{p}} N_p}{\pi\beta^*\left(\varepsilon_p + \varepsilon_{\bar{p}}\right)} H\left(\sigma_l / \beta^*\right)$$

see slide

$$I = \int L dt = N_{stores}\,\tau_L L_0 \ln(1 + T/\tau_L)$$

- Luminosity Integral: primary factors
  - Beta* at IP and bunchlength: H(x)/beta^*
  - Emittances $\varepsilon_p\ \varepsilon_{pbar}$
  - Number of protons: N_p
  - Number of antiprotons: BN_{pbar}
  - Lumi-lifetime: τ_L
  - Number Stores: N_{stores}

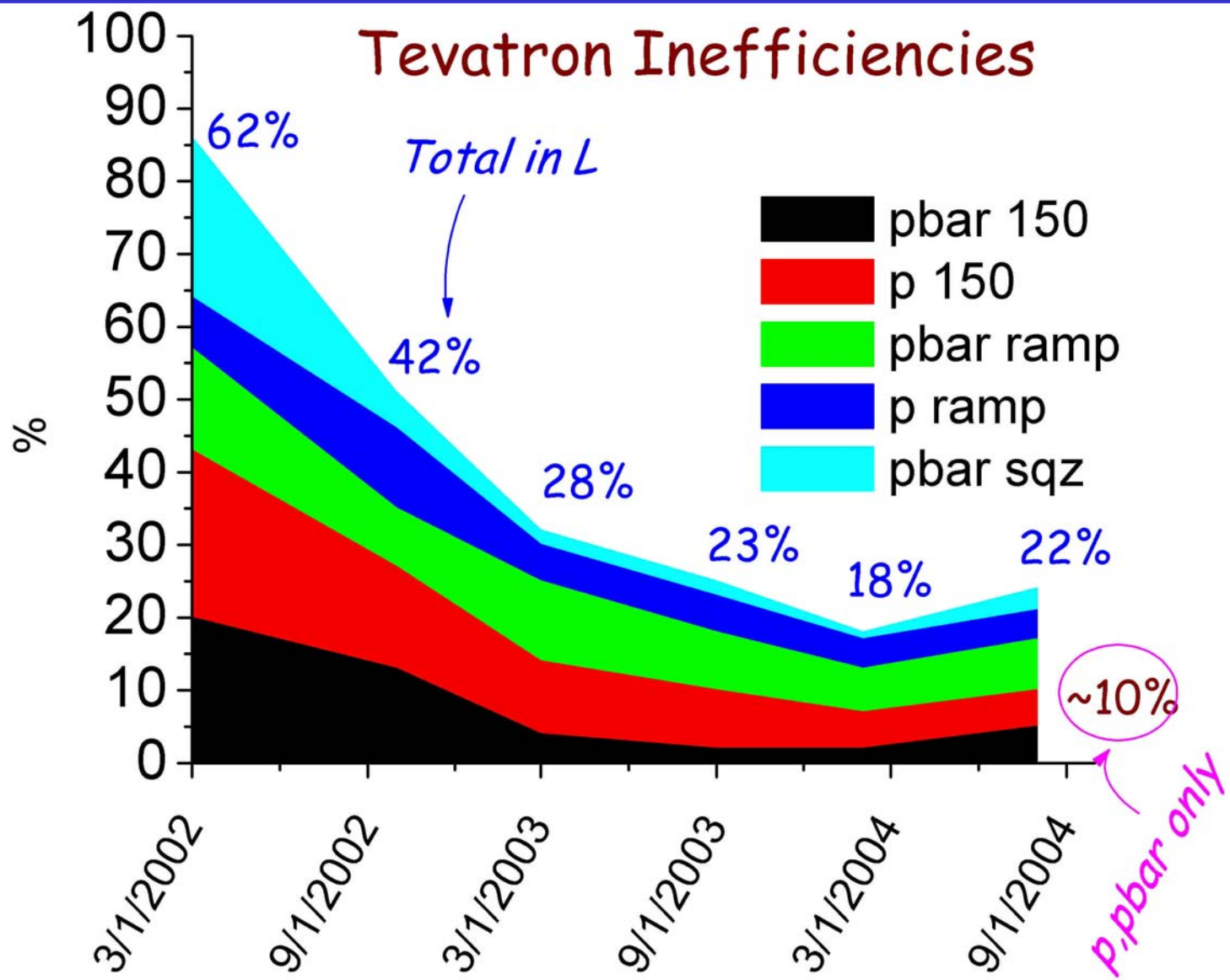
Pbar Only Store: <4% loss from Inj to LB



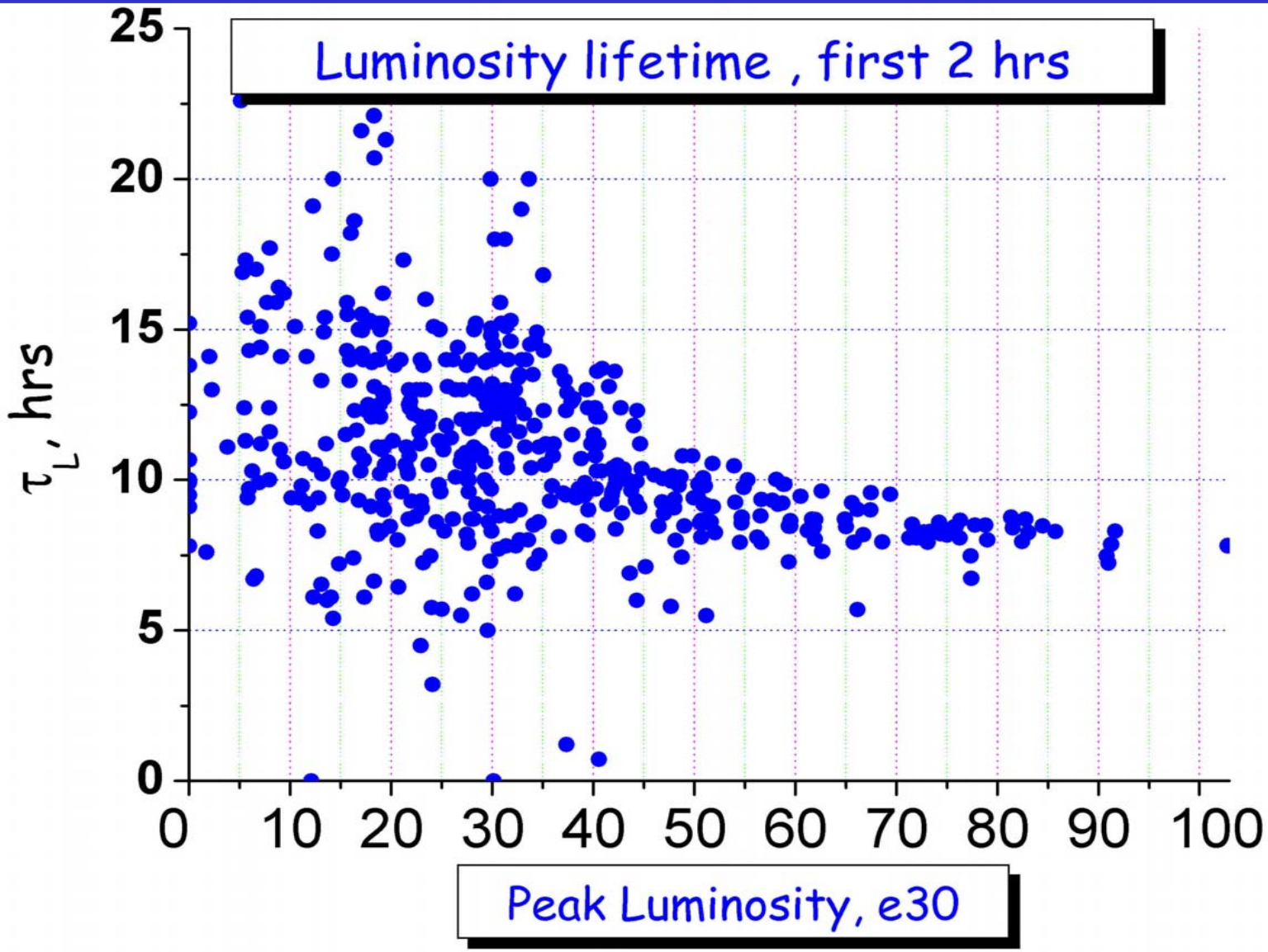
Tevatron Inefficiencies

	10/02	03/03	09/03	02/04	08/04	$\bar{p}$/p only
Record Luminosity, e30	36	41	50	63	107	n/a
Protons/bunch	170e9	205e9	245e9	245e9	250e9	same
Pbars/bunch	22e9	23e9	25e9	30e9	39e9	same
P-loss at 150 GeV	14%	10%	8%	5%	4%	5%
Pbar-loss at 150	9%	4%	2%	2%	5%	2%
P-loss on ramp	6%	5%	5%	4%	4%	3% *
Pbar-loss on ramp	8%	11%	8%	6%	8%	2%
Pbar-loss in squeeze	5%	2%	3%	1%	1%	0%
… at the beginning of store:						
Pbar lifetime at HEP, hr	~40	~35	~35	~30	~25	~900
Proton lifetime at HEP, hr	~90	~60	~20	~100	~70	~300 *
Eff.emittance lifetime, hr	~14	~26	~31	~16	~16	n/a
Luminosity lifetime, hr	~10	~13	~10	~9	~8	n/a

Total $N_a N_p$ Inefficiency in Tevatron



Luminosity Lifetime in Run II



Lifetime Constituents

$$\tau_L^{-1} = \tau_\varepsilon^{-1} + \tau_a^{-1} + \tau_p^{-1} + \tau_H^{-1}$$

(15-20) + (20-25) +(35-210)+(70-80) =(7.5-9.0)hrs

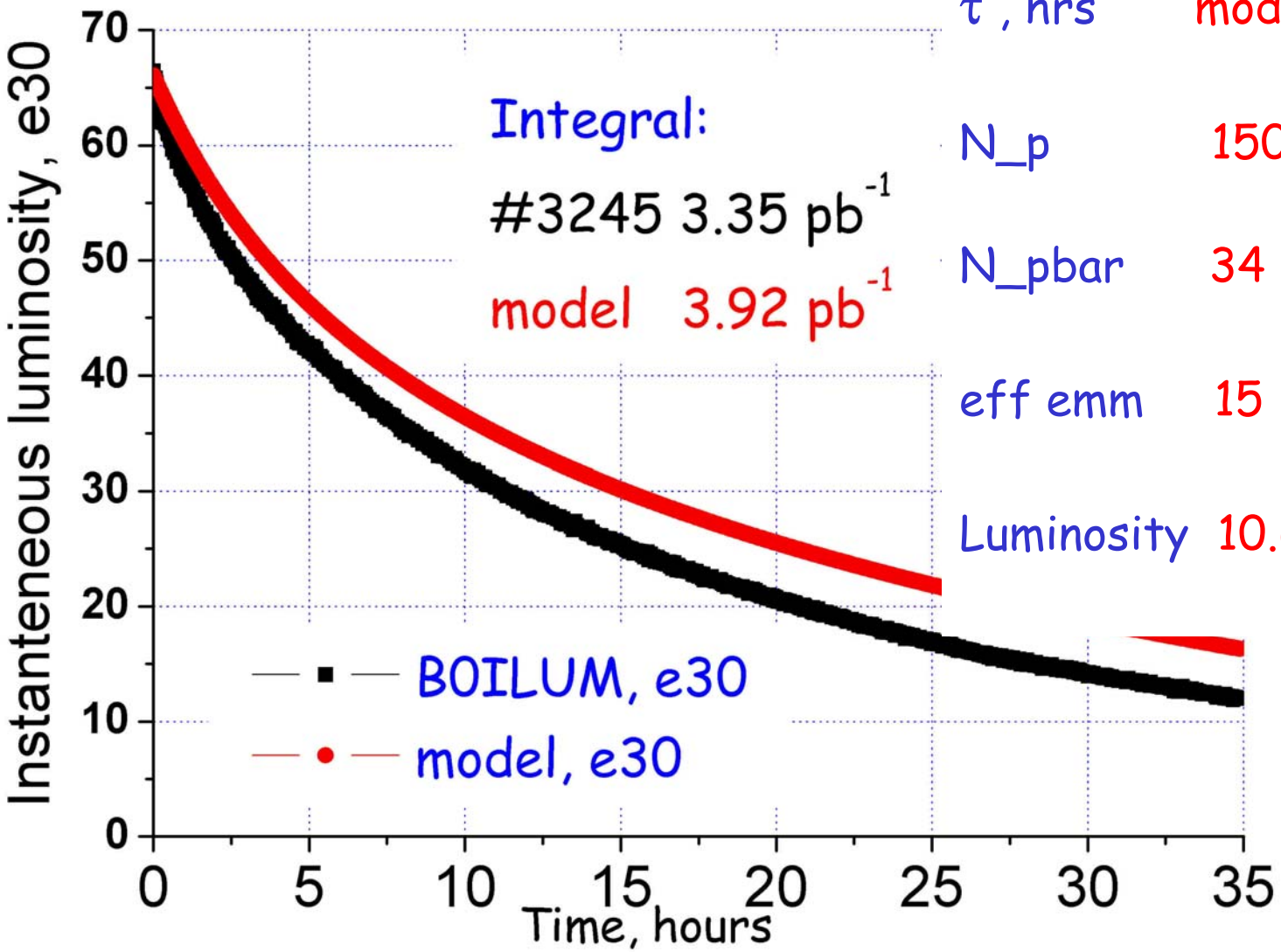
- Emittance growth = 90% IBS + 10% Beam-Beam Effects
- Pbar lifetime = (70-80)% burnup + (20-30)% Beam-Beam
- Proton lifetime = 80% Beam-Beam + 20 % burnup
- Hougrlass lifetime = 90% IBS + 10 % Beam-Beam

IBS determines ~50% of the lifetime

Burn-up due to luminosity – another 30-35%

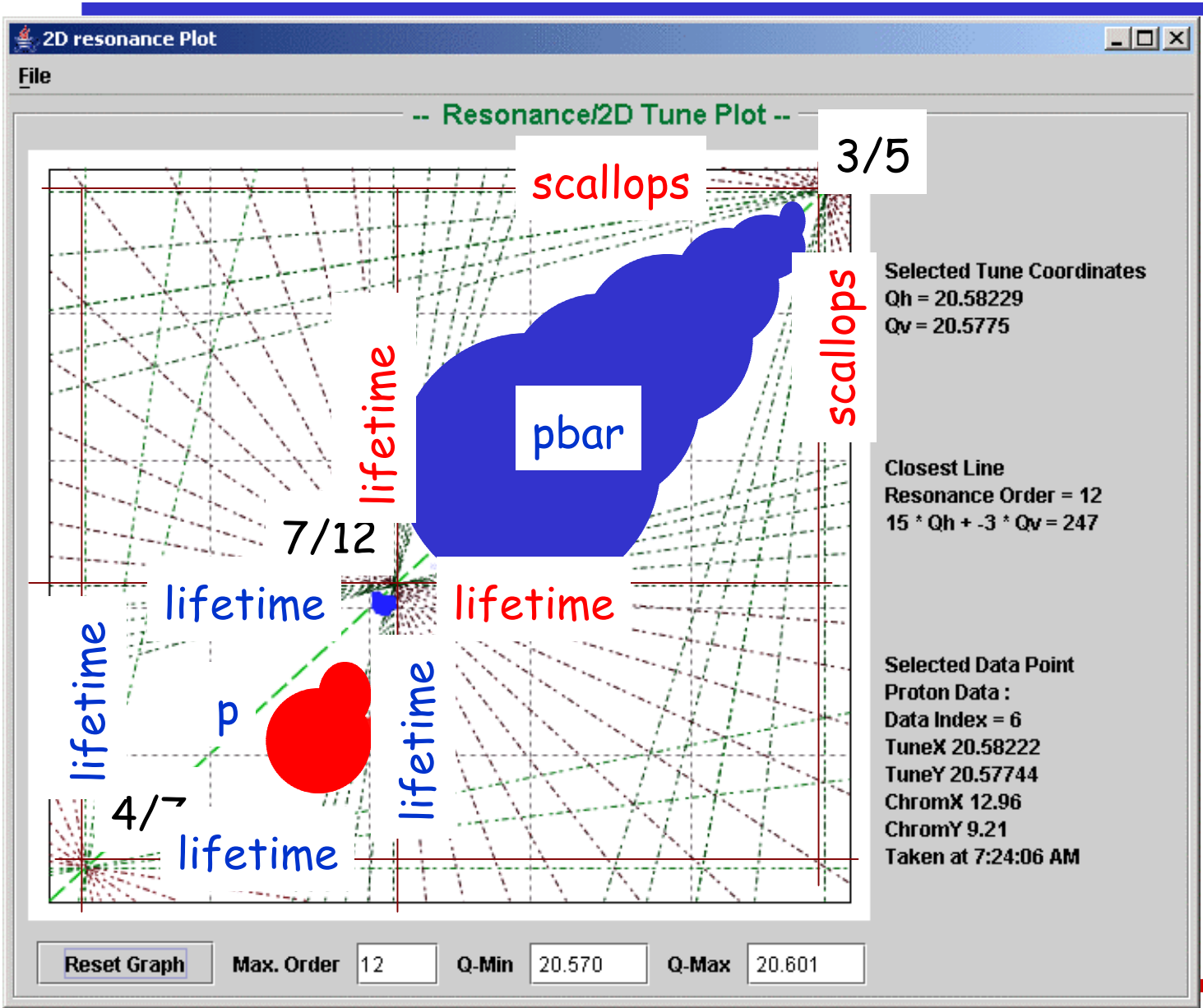
Beam-Beam Interaction reduces lumi- lifetime by 15-20%

Model w/o Beam-Beam and Store 3245



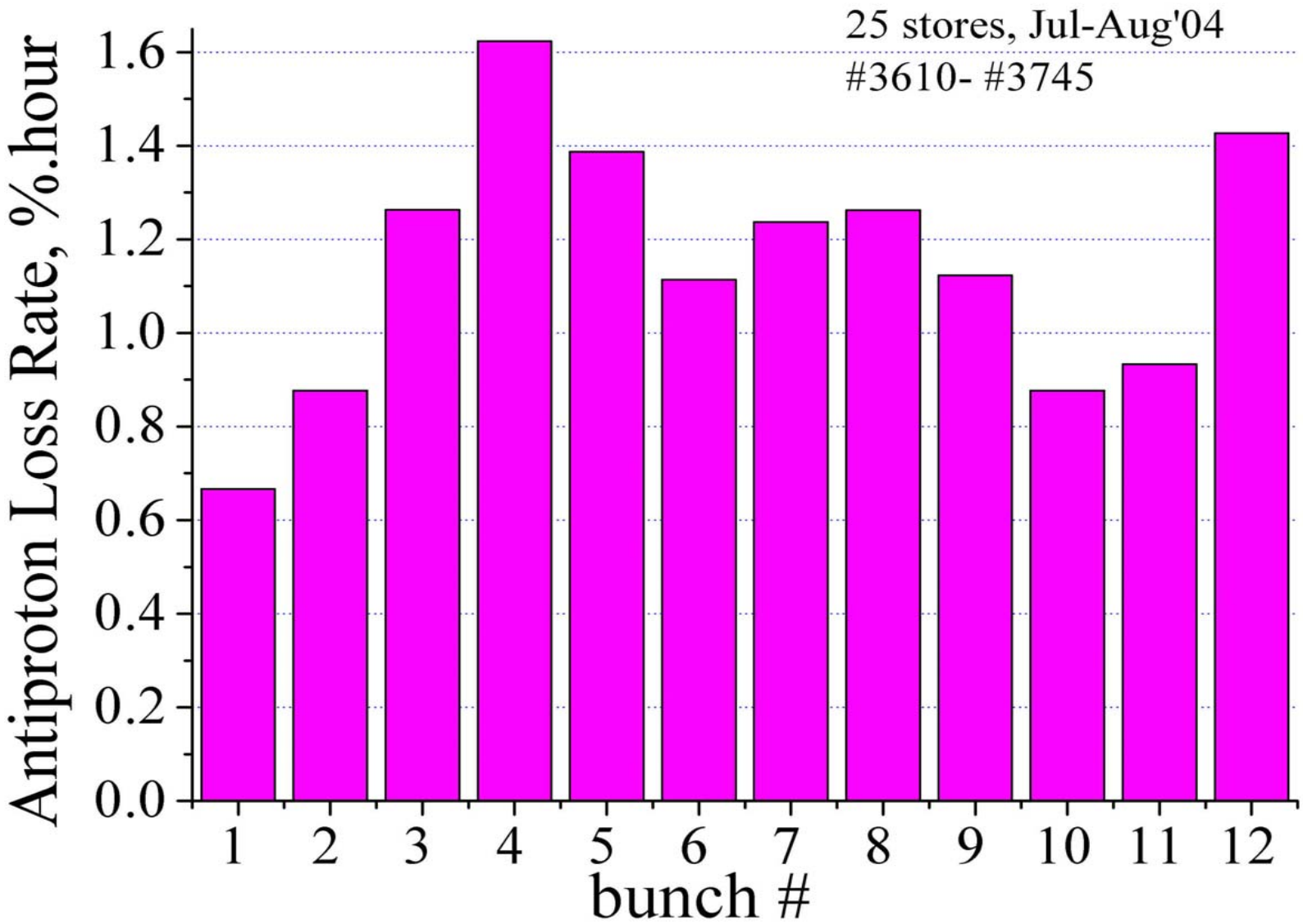
τ , hrs	model	#3245
N_p	150	150
N_pbar	34	32
eff emm	15	12
Luminosity	10.6±1	8.2

Betatron Tunes (Working Points)

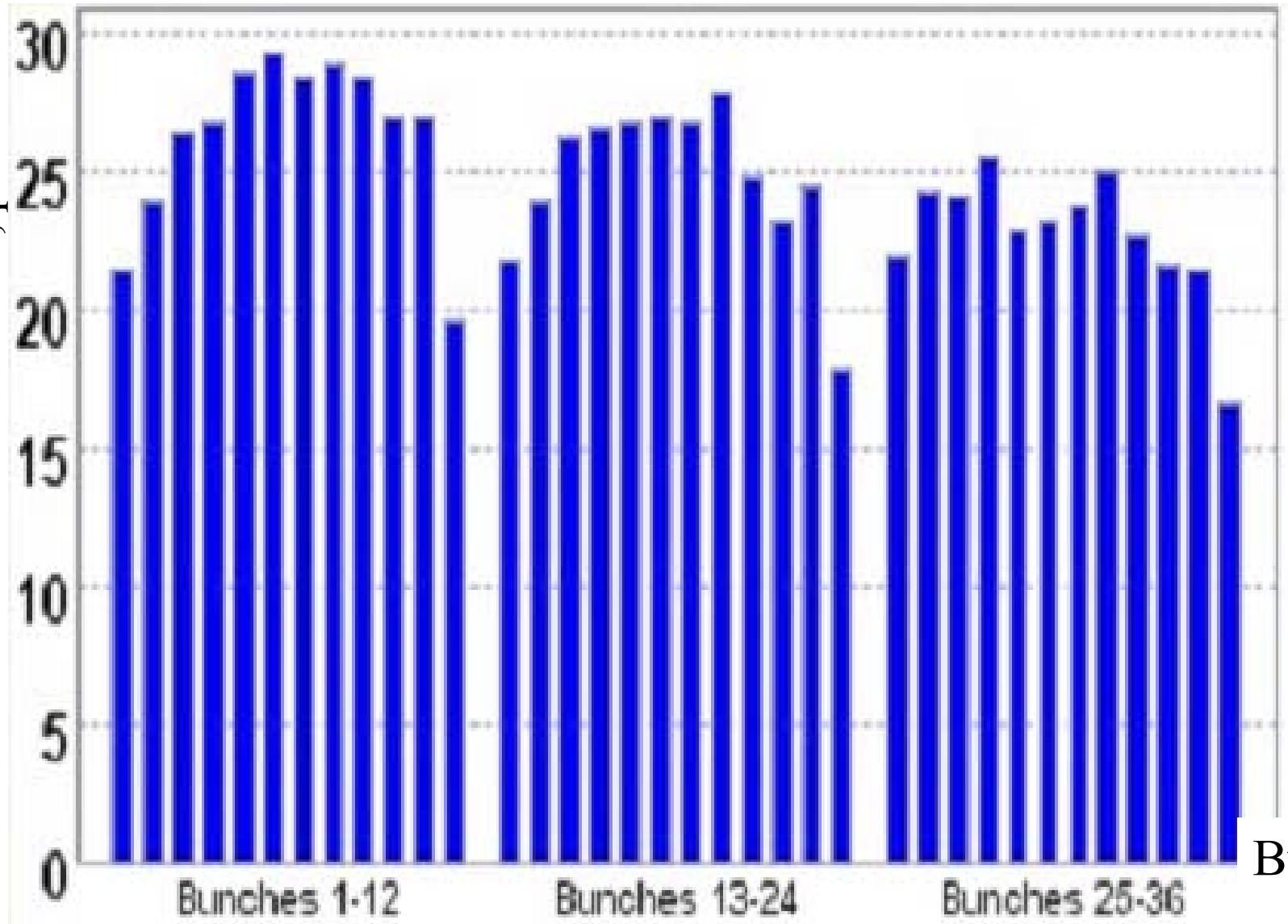


- Balancing btw major resonances

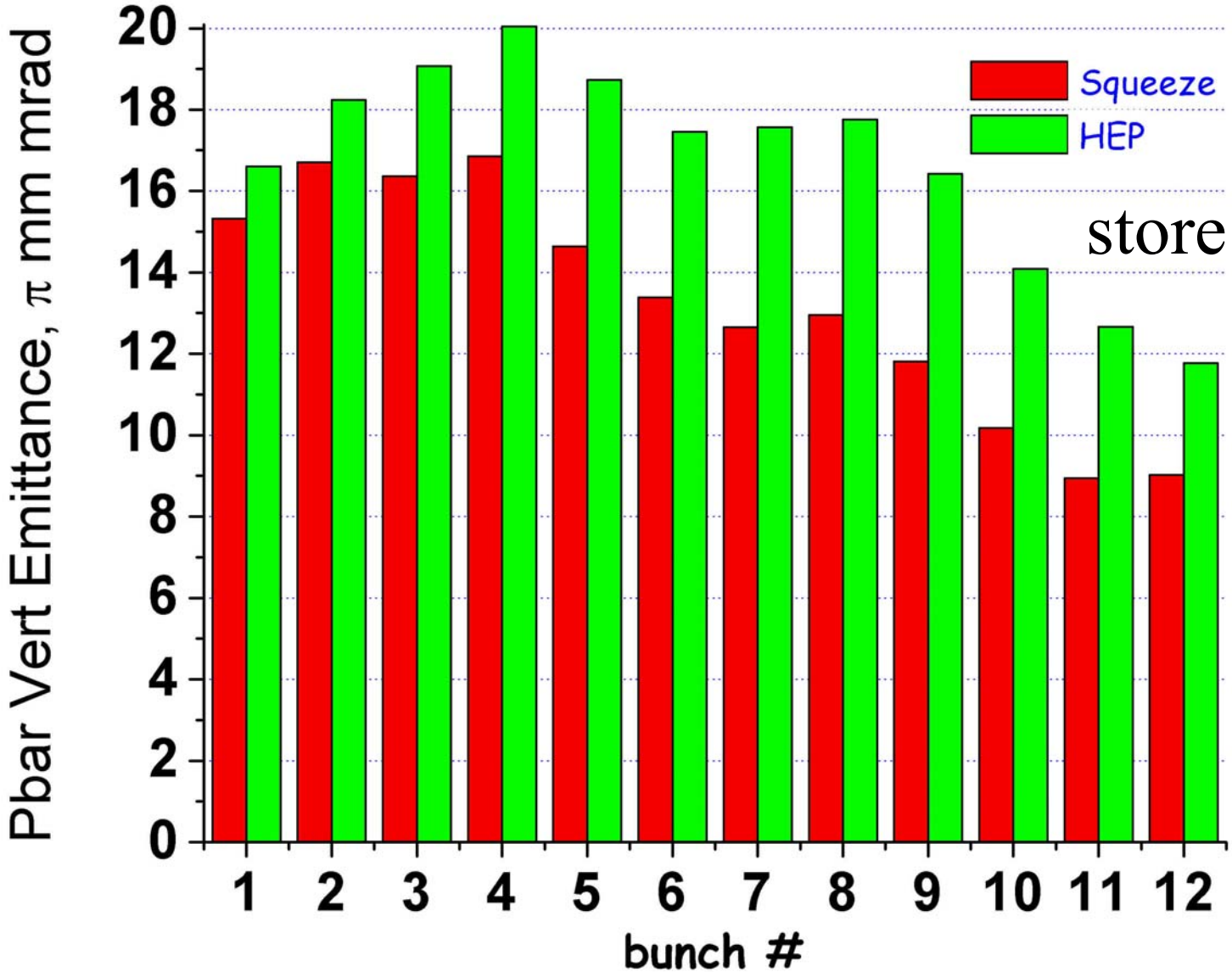
Non-Luminous Antiproton Losses



"Scallops" in Pbar Bunch Emittances

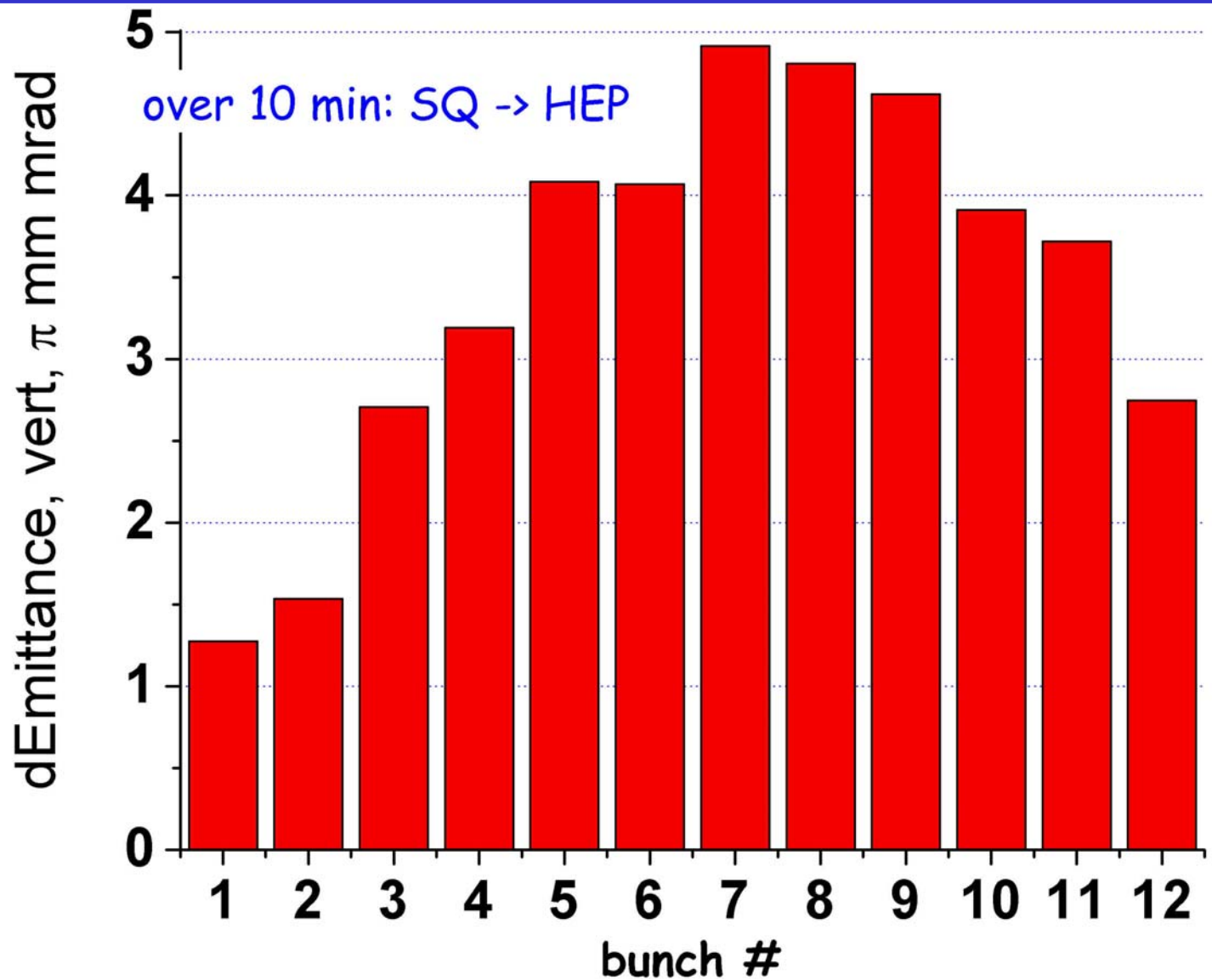


"Scallops": Pbar Emittance

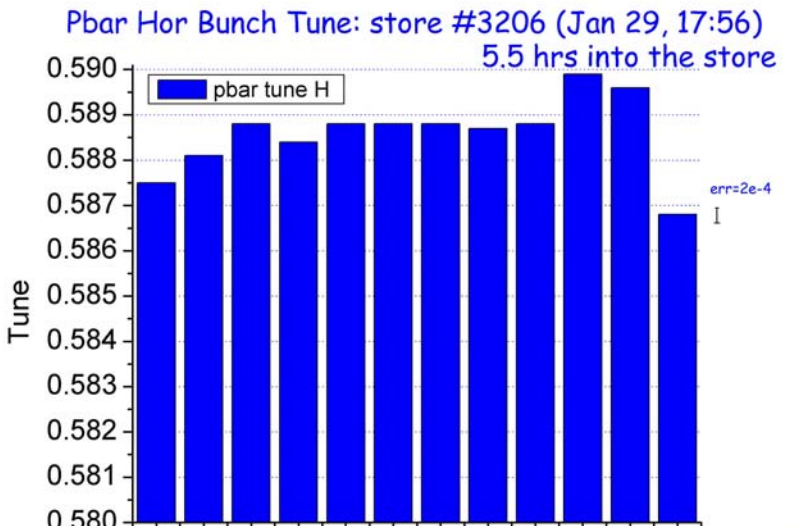


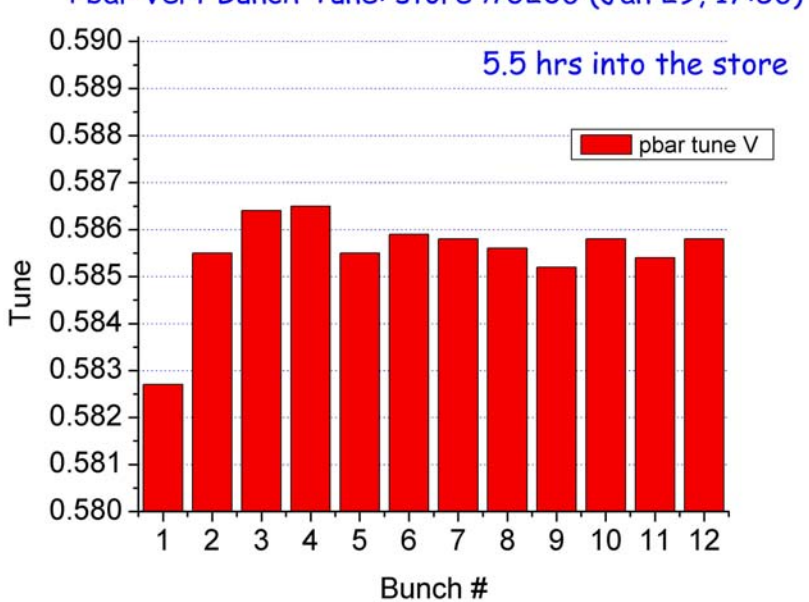
store #3231

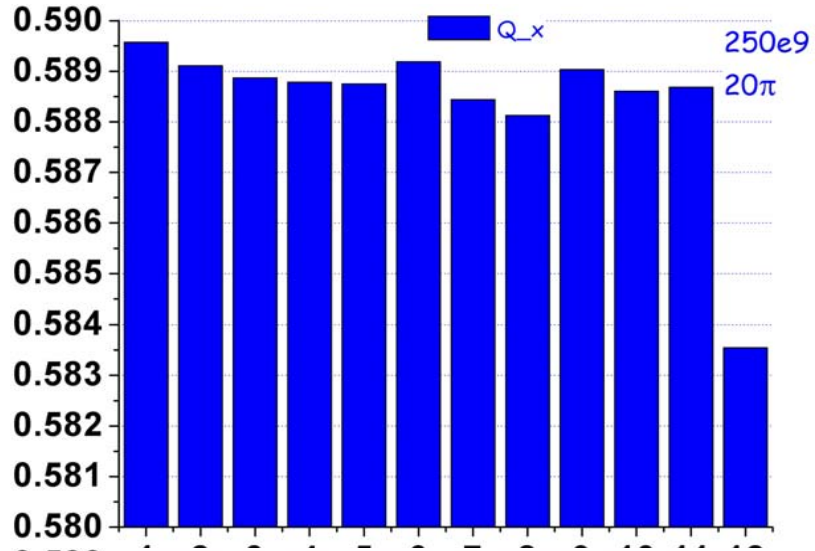
Pbar Bunch Emittance Growth

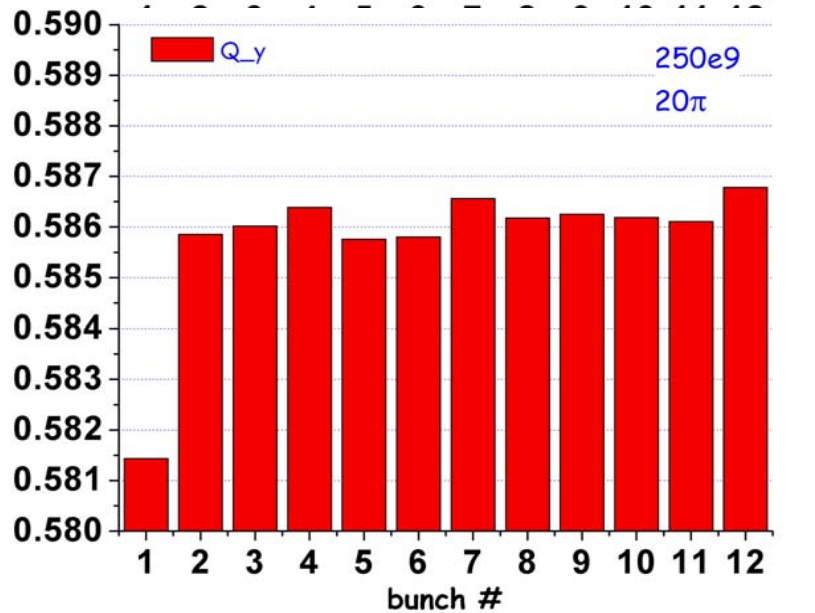


Measured vs Calc'd Pbar Bunch Tunes

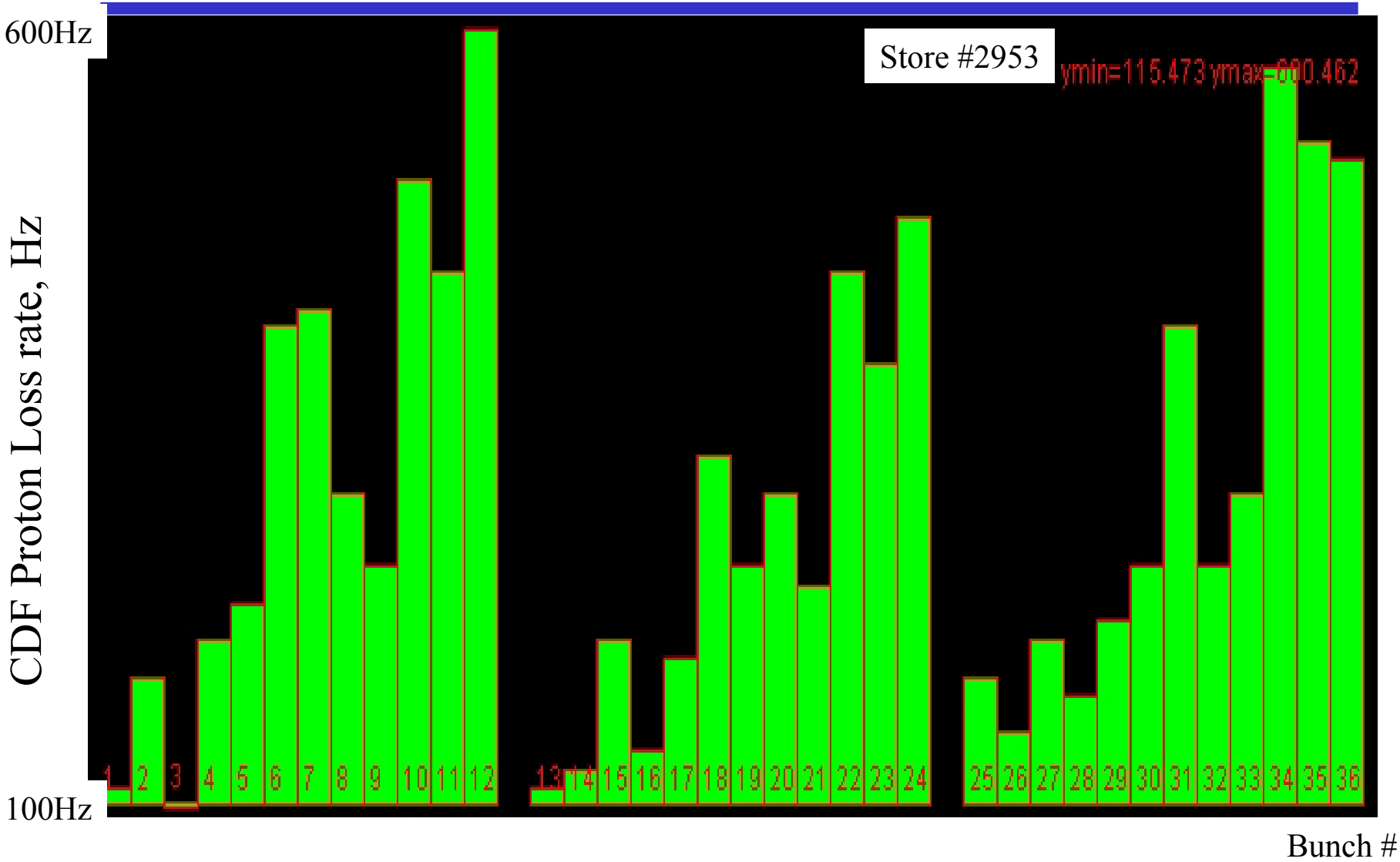




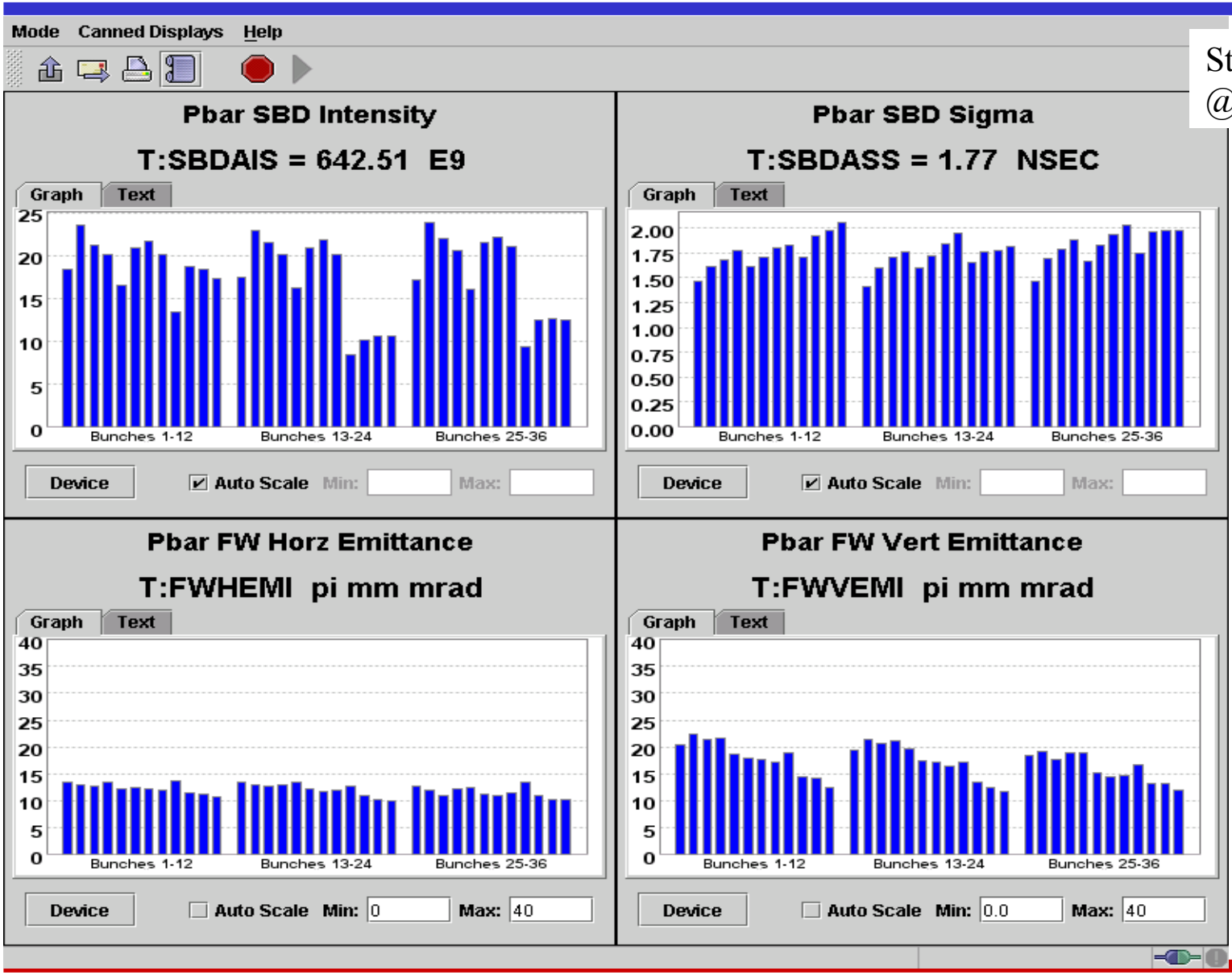




Proton losses induced by Pbars

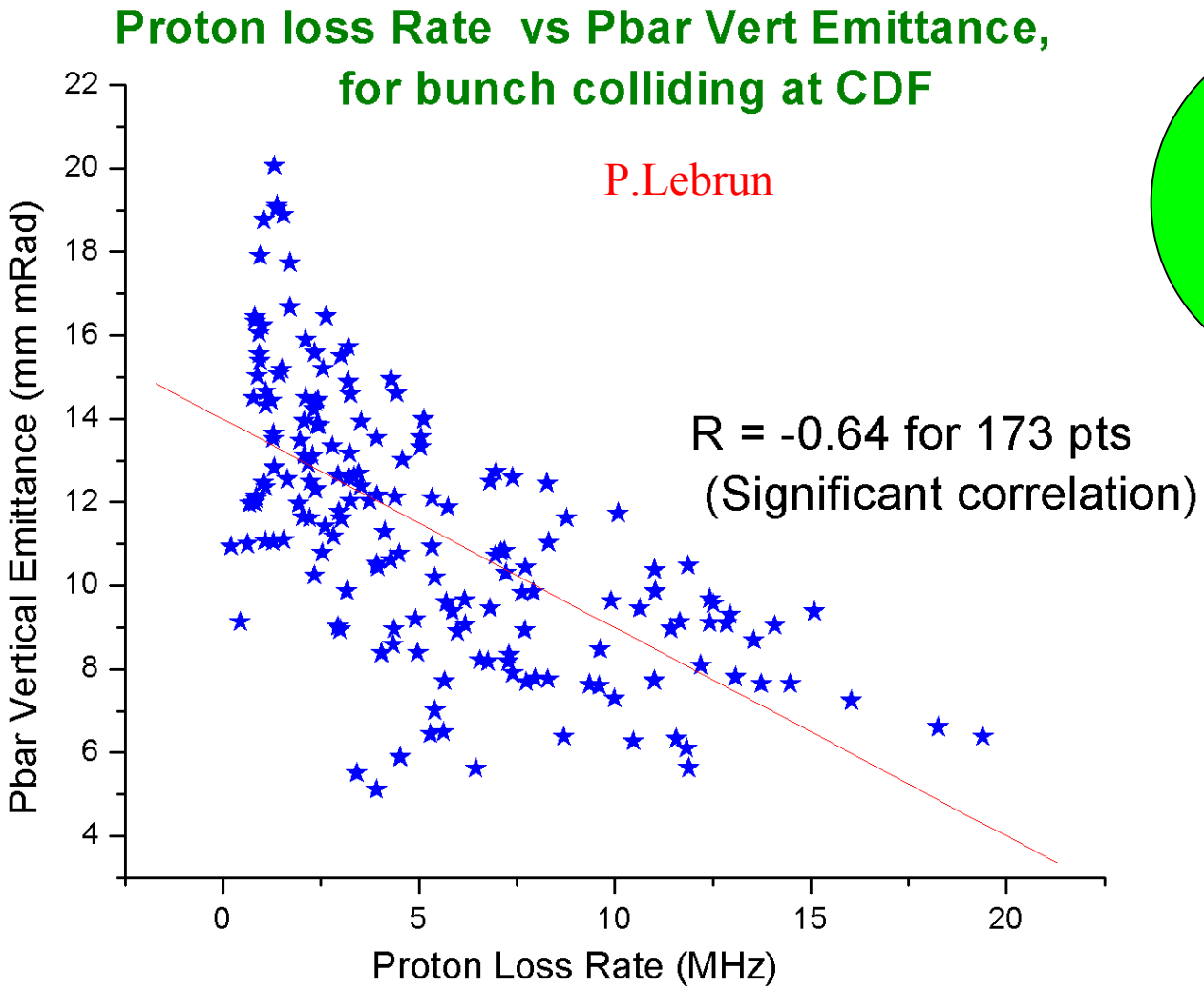


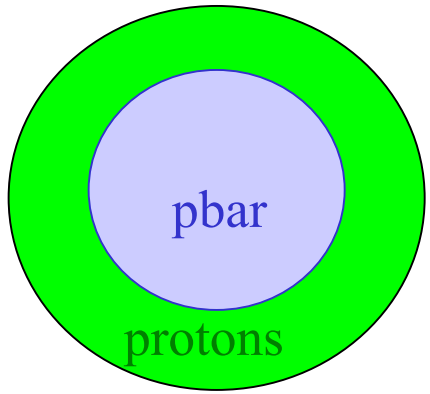
Pbar bunch intensities and sizes VARY (from AA)



Store #2932
@ HEP

Loss of protons due to pbar non-linearities





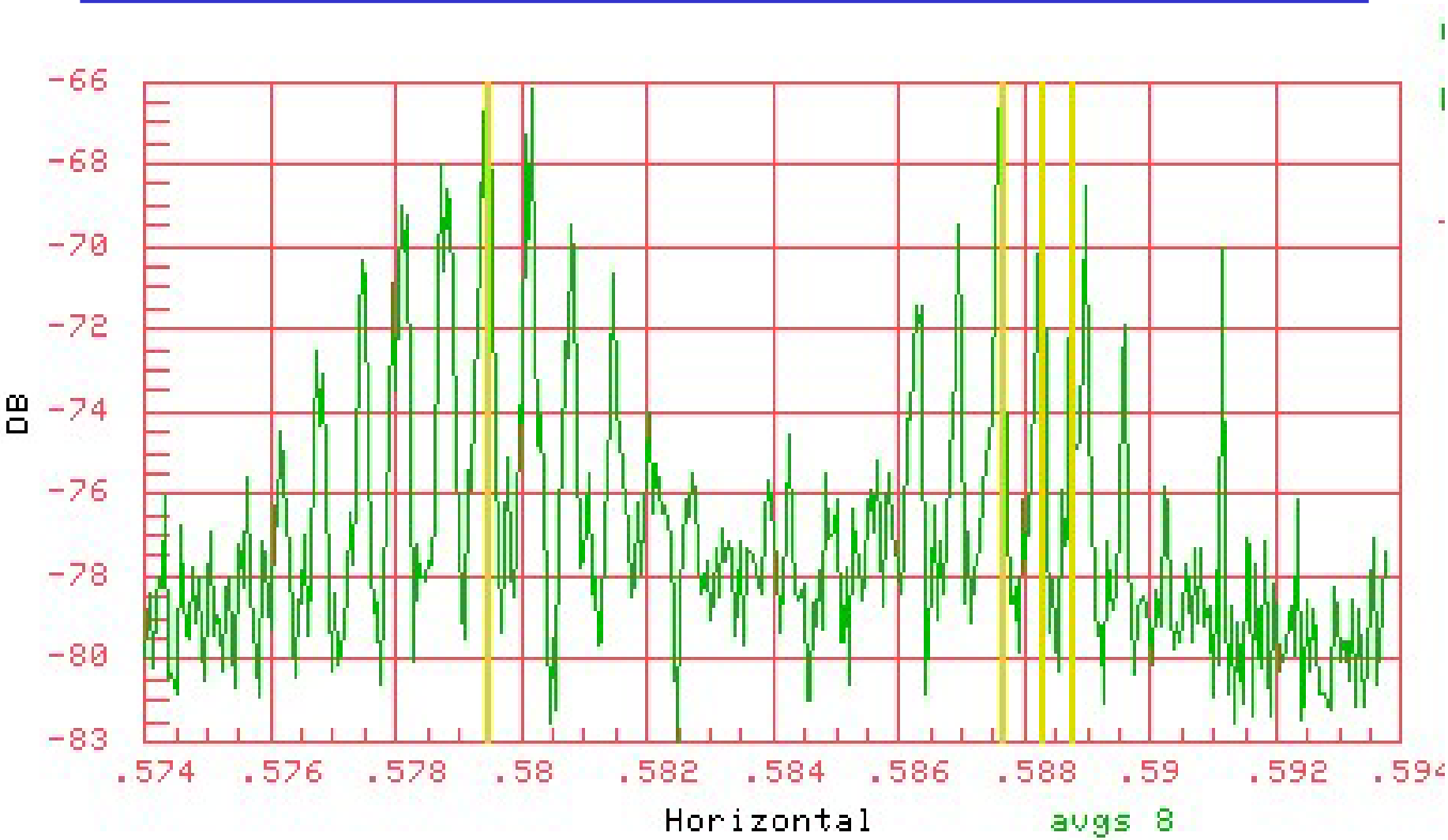
Where TEL(s) can be helpful?

- Not much at 150 ramp and squeeze:
  - conditions change too fast for present diagnostics and foreseen improvements
  - Bunch-by-bunch effects not very prominent (all parasitic IPs are more or less equally important)
  - Too many other important factors to be addressed before BBC (orbits, apertures, vacuum, chromaticities, FWs, helix, etc)
- In collisions
  - Some 15-20% of luminosity integral is on stake
  - Scallops
  - Pbar bunch-by-bunch lifetime
  - Proton along-the-train lifetime
- DC beam cleaning at all stages (see below)
  - 300W CW kicker is nowhere close to TEL efficiency
  - TEL-2 is needed as an operational spare

So, What about TEL so far?

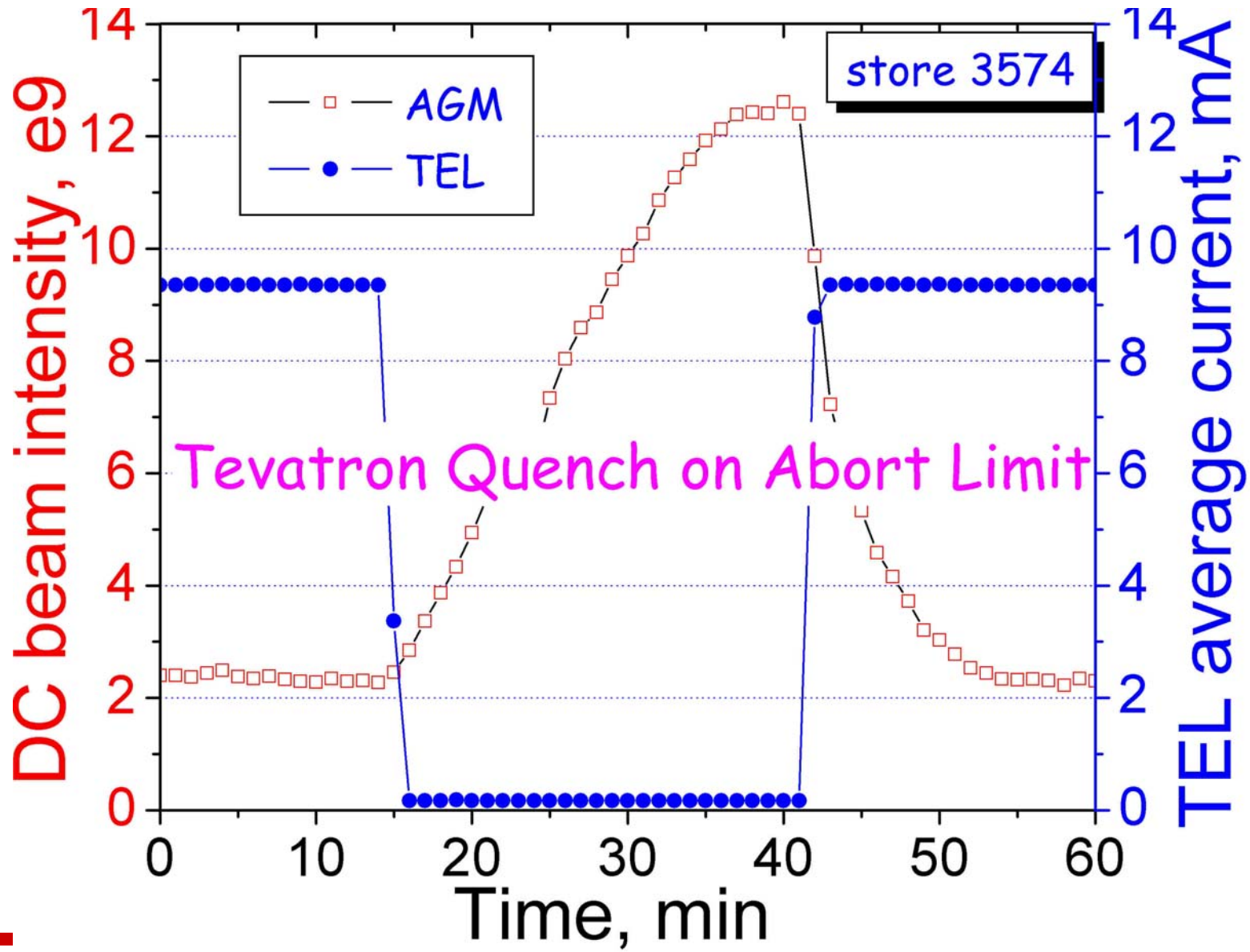
- Accomplishments to date:
  - summary below (3 slides only)
  - XL Zhang, "Experiments with TEL"
- TEL-1 in Operation
  - XLZhang
- Hardware Issues
  - V.Shiltsev, e-beam hardware
  - A.Klebaner, cryogenics
  - M.Olson, BPMs
  - CYTan, tune measurements
  - Yu.Tereshkin, HV modulator
- Next Steps, Plans, etc
  - V.Shiltsev

Tuneshift dQ_{hor}=+0.009 by TEL

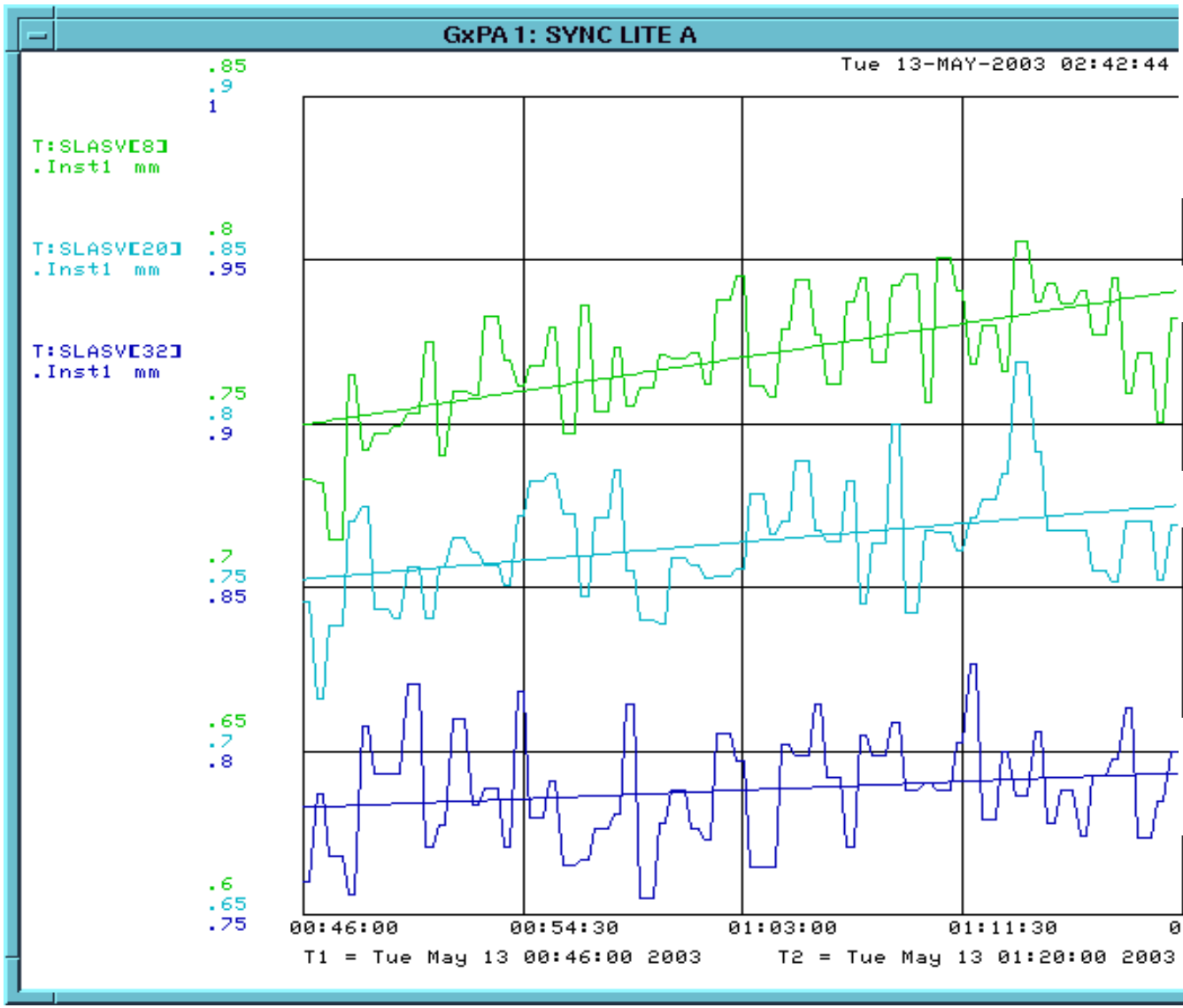


Three bunches in the Tevatron, the TEL acts on one of them

DC Beam in Abort Gap:TEL On/Off/On



TEL Suppresses Pbar V-Size Growth: ½ hr in store



Store #2540

May 12, '03

A9 : 4.1 p mm mrad/hr

A21 : 2.2 p mm mrad/hr

A33 : 1 p mm mrad/hr

-TEL on it

Prerequisites

- Hardware
  - TEL-1 and TEL-2 for full compensation experiments
  - Proper e-gun (currently though to be SEFT gun)
  - Powerful enough HV pulser
  - Spares
- Diagnostics and Controls
  - BPMs assuring <0.2 mm e-p or e-a alignment in 4 points
  - A and P bunch-by-bunch tune measurement system with resolution <2e-4 every minute
  - Low-noise A and P bunch-by-bunch monitors – intergrated SBDA(P)I(S)S, B0PLOS, D0AHTL, B(D)0ILUM, etc
  - ACNET controls, slow feedbacks to track parameters in store
- Time
  - To install TEL-2 (>2 wk shutdown)
  - MD studies with TEL-1 and TEL-2